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Comprehensive Cloud-based Nuclide Identification for Handheld Gamma-Ray Spectrometers

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Final Report

Comprehensive Cloud-based Nuclide Identification for Handheld Gamma-Ray Spectrometers

Project number: LL13-CompCloud-PD2Jh

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1. INTRODUCTION

Nuclide identification algorithms operating on handheld gamma-ray spectrometers suffer from poor algorithm design, incorrect and incomplete nuclear data, limited computational capability and calibration issues. A one-year feasibility study was conducted in collaboration with Idaho National Laboratory (INL) to investigate a secure "Cloud-based" nuclear identification system that automatically uploads measurements from the instrument and provides comprehensive automated analysis. The analysis employed was too computationally difficult to run on handheld instruments, but runs quickly on a computer systems accessed from the cloud-based server. The analysis uses advanced radiation analysis codes developed at LLNL. Encounters with radioactive sources are automatically detected and an optimized solution for the nuclide mixture, shielding and scattering are computed and downloaded to the user on any internet-device they choose such as a smart phone, tablet or laptop computer. A comprehensive plan was developed and an operational demonstration was presented September 11, 2013 at RSL Andrews.

2. RESULTS

The project was originally proposed in three tasks with the primary focus on providing the necessary algorithms. At the request of NA-22, this project was merged with the INL project "Leveraging the Cloud for Analysis of Radiation Detector Data" webPMIS PROJECT NUMBER: IN13-LeverCloud-PD03, PIs Jason Wright and David Chichester. Some realignment of the task schedule was required to apply the LLNL cloud-based capabilities within the INL data taking and logging structure. This realignment included adding new tasks to interface the analysis algorithms with the actualized cloud-based measurement system, and moving some of the more advanced aspects of the analysis algorithms to a follow-on effort. The overall product now includes a full measurement and analysis system, and is therefore more complete.

Task 1. Automated calibration algorithm development

The automated calibration, as well as the automated spectral analysis, requires a high sensitivity, highly controllable source detection algorithm. Detector calibration drifts with environmental conditions, battery condition, etc. and detector response can change due to aging, handling, etc. The detailed characterization of detector response is often limited and calibration updates are not always provided. Furthermore the characteristics of radiation background can change with location, time, etc. The auto-calibration and background analysis is designed to compensate for these issues.

The auto-calibration uses continuous monitoring or the detectors to update the calibration when appropriate. The detection metric separates background from sources. The background is used to update the background characteristics, such as spectra shape and intensity, which are needed to update and improve the detection metric. The background is also used for the “dynamic” calibration where the gain and offset are adjusted regularly to account for the overall gain drifts and other daily changes. When strong sources with high confidence identification are encountered, they can be used to update the higher-order detector characteristics. This is the “static” calibration since it generally does not change as quickly, as the overall gain, but can change significantly during the lifespan of the detector. This “static” calibration includes the non-linear corrections and energy resolution. The auto-calibration was partially implemented for the operational demonstration presented September 11, 2013 at RSL Andrews, and the framework was completed to allow full implemented in the next phase proposed for FY14.

The background suppressing detection metric employed for the NaI detectors was the Spectral Anomaly Algorithm (SAA), one of several techniques available in Radiation Detection Analysis Kit (RDAK). The SAA was updated for the test detectors and implemented in the cloud-based system used in the September 11, 2013 operational demonstration. The SAA was also tested using other NaI-based measurements including extensive dataset from the Aerial Measurement System (AMS). The AMS data provides a challenging test with very large background variations with intensity variations as large as a factor of five in the transition between flying over land and over water, with a very large change in spectral shape as well. This version of the SAA was the generalized spectral anomaly without threat targeting. It will detect any spectral shape including those that do not correspond to real sources with equal sensitivity. Matched filter and other techniques can be added to enhance sensitivity to know threat objects. For the HPGe detectors a k-sigma algorithm was used to provide a detection metric. A spectral-based detection metric for HPGe has been outlined for the next phase proposed for FY14.

Task 2. Automated spectral analysis with physics-based forward modeling development

Two automated spectral analysis codes were implemented and demonstrated during the September 11, 2013 operational demonstration. For the NaI spectra the Radio-Nuclide Analysis Kit (RNAK) developed at LLNL was used. In RNAK, nuclide identification is formulated as an optimization problem and known large-scale optimization techniques are used to find all of the best identification solutions that are consistent with the measurement. Most other approaches to nuclide identification provide only one solution, but for many of the most important cases there are often several reasonable solutions that are consistent with the limited quality of typical measurements. Each of these solutions can then be run with the iterative model solver to find the best overall solution. A Bayesian optimization algorithm that uses a large-scale optimization branch and bound algorithm is used to analyze spectra with arbitrary mixtures of nuclides.

For the HPGe detectors, automated spectral analysis was provided by a modified version of HPGeID, an automated analysis component of the LLNL Gamma Designer analysis code. HPGeID applies an expert-system approach to analyzing measured line energies and ratios. It provides descriptive analysis and highlights ambiguities and discrepancies. It was modified to also provide summary nuclide ID conclusions needed for the automated result, and all the output were adjusted to comply with the N-42 format. In addition to the nuclide summary, it provides a wealth of information useful to the user. Some example outputs are:

- Am-241, Med/indus w/Pu-239-lone 60 keV line, confidence high
- Unshielded Pu-241/U-237 likely, confidence high
- 59 & 208 keV daughter U-237 lines identified
- U K x-rays from Pu decay, confidence high
- Pu-239, Fissile -- 4pks, w/unshielded Am-241, Grade indeterminate
- No Key neutron activation peaks manifest but Pu indicates neutrons are present
- No Other Key alpha-X peaks or alpha-n peaks found

Task 3. Test problem set creation and performance evaluation

During the September 11, 2013 operational demonstration, data were accumulated live with eight detectors running at Idaho Falls, and two detectors operating at RSL Andrews. All data were collected in the cloud and analysis applied with the algorithms developed in task 1 and 2. An extensive collection of simulated nuclear threat spectra have been extracted from models. These simulated threats cover a wide range of objects of interest including SNM in shielded configurations that could be used for smuggling. Software to inject these signatures into the data collected around the operational demonstration has been developed and ready for implementation in the next phase proposed for FY14.

3. DISCUSSION AND CONCLUSIONS

All three tasks were completed successfully and demonstrated during the September 11, 2013 operational demonstration at RSL Andrews. The auto background collection and dynamic (low order) auto-calibration have been implemented and demonstrated in a cloud-based system. The ongoing update of static (high-order) calibration and spectral anomaly basis set are ready for implementation. Spectra and background useful for this are identified using the Radiation Detection Analysis Kit (RDAK) Spectral Anomaly Algorithm (SAA). This was demonstrated for the NaI detectors and a HPGe version is ready for implementation, as are the localization algorithms.

NaI spectral analysis with the RadioNuclide Analysis Kit (RNAK) is operational and only requires some fine-tuning. A full GUI display is ready for implementation. HPGe spectral analysis was implemented with the Gamma-Designer HPGeID. Some fine-tuning is required, and a more complete machine-learning based implementation is under development.

The necessary algorithms are all ready to be implemented for a full performance analysis using the LLNL Surrogate Nuclear Models (L-SNM). A comprehensive plan was delivered that would further develop these capabilities and integrate them into the emergency response data collection system.

4. PATH FORWARD

A comprehensive proposal was submitted to use the results of this project to develop a new capability for nuclear emergency response that takes advantage of state-of-the-art advances in computer science, information technology, signal processing, and digital communications. This system would continuously ingest data from a variety of sensors in the emergency response area and in real time automatically provide detection, localization, identification, and preliminary diagnostics of all radiation sources encountered. The system would analyze data from stationary and mobile radiation sensors, including measurements obtained autonomously from unattended instruments placed at strategic locations, mounted in vehicles, or carried by personnel not engaged in nuclear search thus providing much more wide-area coverage. The system would provide response personnel with alerts on potential threats, along with full situational awareness, including locations of sensors and sources with, identification, and preliminary diagnostics information. All analysis would be assigned confidence levels and the system will provide suggestions for additional measurements to improve the analysis further. This proposal is currently “on hold” in the WMS DNN R&D.

5. PRESENTATIONS AND PUBLICATIONS

“Leveraging the Cloud For Analysis of Radiation Detector Data.” Poster presented April 9, 2013 at the Nuclear Weapons & Material Security Team Program Review Meeting April 10, 2013 at Sandia National Laboratory in Livermore, CA.

“Leveraging the Cloud for Analysis of Radiation Detector Data: A Joint INL-LLNL Project for Nuclide Identification for Gamma-Ray Spectrometers” was presented along with operational demonstration by the LLNL/INL project team on 11 September 2013 at the Remote Sensing Laboratory, Andrews Air Force Base.